Impact of Trawling on the Benthos Around Oil and Gas Pipelines

Scottish Marine and Freshwater Science Vol 9 No 13

M Harrald, P J Hayes and M Hall
Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland’s seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publishes results of research and monitoring carried out by Marine Scotland Science. It also publishes the results of marine and freshwater scientific work that has been carried out for Marine Scotland under external commission. These reports are not subject to formal external peer-review.

This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

© Crown copyright 2018

You may re-use this information (excluding logos and images) free of charge in any format or medium, under the terms of the Open Government Licence. To view this licence, visit: http://www.nationalarchives.gov.uk/doc/open-governmentlicence/version/3/ or email: psi@nationalarchives.gsi.gov.uk.

Where we have identified any third party copyright information you will need to obtain permission from the copyright holders concerned.
Impact of trawling on the benthos around oil and gas pipelines

Dr Marion Harrald*, Dr Peter J. Hayes and Dr Malcolm Hall

Marine Scotland Science, Marine Laboratory, 375 Victoria Road, Aberdeen, AB11 9DB, UK,
*corresponding author: marion.harrald@gov.scot

Abstract

Where fisheries actively target specific areas there may be a disproportionately higher impact on the seabed than in less targeted areas. Previous analysis of VMS data has demonstrated a high level of fishing around oil and gas pipelines in the North Sea. This is thought to be due to a reef effect which attracts fish to the pipeline. We present side scan and photographic imaging which clearly reveals evidence of bottom trawling within an area of 500 m either side of the pipelines. Investigation of individual photographs on transects running over the pipeline, point towards evidence for a reduction in benthic fauna on seabed where there are trawl marks compared to seabed where there are not. This likely effect is also evident on sea pens which were commonly found on the muddier ground in the survey areas. Two of the most frequent biotopes, “burrowed mud” and “sea pens and burrowing megafauna in circalittoral fine mud”, are the focus of conservation efforts through OSPAR and as ‘Priority Marine Features’ in Scottish waters. As the North Sea is a mature basin for exploitation of oil and gas, many pipelines are being considered for decommissioning. We consider the implication of this benthic impact of fisheries on decisions for pipeline decommissioning.

Introduction

Two widespread human activities in the North Sea are commercial fishing and exploitation of oil and gas resources. Where these activities overlap there is potential for interaction. The North Sea is an intensively fished marine ecosystem (Jennings et al., 1999) and fishing gear is known to impact the benthic fauna (Dayton et al., 1995; Tuck et al., 1998; Jennings and Kaiser, 1998; Kaiser and Spencer, 1996). It is reported that there are over 45 000 km of oil and gas pipelines, cables and umbilicals in the North Sea (Oil and Gas UK, 2013). While safety zones (500 m radius) exist around offshore oil and gas infrastructure in which fishing is restricted, there are no such restrictions around pipelines. Some pipelines are installed proud of the seabed and have the potential to interact with commercial fishing gear (Oil and Gas UK, 2013). Where snagging hazards exist, operators will cover the pipeline using rock dump or concrete mattresses. Analysis of Vessel Monitoring System (VMS) data and pipeline position has shown that far from avoiding the pipelines, some fisheries appear to actively target them (Rouse et al., 2017; Osmundsen and Tveteras, 2003). Anecdotally, it is thought that the pipelines create a shelter on a largely featureless seabed and consequently generate localised enhancement of fish caused by a reef effect (Hunter and Sayer, 2009). If these areas surrounding pipelines are favoured by fisheries, as is reported by Rouse et al. (2017), this may create a high degree of fishing intensity on the habitats within these grounds. OSPAR Decision 98/3 requires the removal of offshore platforms for re-use, recycling or final disposal on land unless a permit allowing derogation from the terms of the decisions is submitted. However, the decision of whether and how pipelines
are decommissioned lies at the discretion of individual Member States. Where pipelines are being considered for in-situ decommissioning a comparative assessment approach will be applied taking into consideration safety, environmental, technical, societal and cost components.

The seabed habitats found offshore in the northern North Sea are predicted to be mud, sand, coarse and mixed sediments (EMODnet, 2017). Deep mud habitats in the North Sea (10 to 500 m) are an important habitat for burrowing species such as the prawn Nephrops norwegicus, Actiniaria (the anemones), Holothurians (the sea cucumbers) and Pennatulids (the sea pens) (Wilding et al., 2016). The richness of mud habitats has afforded their protection in UK waters. ‘Mud habitats in deep water’ are priority habitats for UK Biodiversity Action Plans as a part of the Scottish Biodiversity Strategy (Mud Habitats in Deep Water, 2008). The habitat ‘burrowed mud’ (including all component biotopes and species) has recently been included as a ‘Priority Marine Feature’ (PMF) (Wilding et al., 2016), a focused list of habitats important in Scottish waters arising from The Marine (Scotland) Act 2010. The habitat “sea pens and burrowing megafauna communities” is also listed as key conservation importance under Annex V of the 1992 Oslo Paris Convention (OSPAR, 1992). Three species of sea pens exist in Scottish waters, Pennatula phosphorea (phosphorescent sea pen), Virgularia mirabilis (slender sea pen) and Funiculina quadrangularis (tall sea pen) (Greathead et al., 2007). Being erect and fragile, sea pens are particularly vulnerable to mobile fishing methods (Tuck et al., 1998; Greathead et al., 2005).

Recent VMS data (2009 to 2013) display evidence for high levels of mobile demersal fishing for ground fish, Nephrops and scallop in the northern North Sea (NMPI, 2017). Trawling on muddy ground causes a significant level of disturbance to the seabed in an otherwise low energy environment (MacDonald et al., 1996). Nephrops trawls, for example, have low head-lines and the mouth of the net skims the seafloor with a heavy grass rope and small bobbins. Dragging the trawl scrapes the seabed and removes or flattens epifauna leaving the seabed highly modified (Magorrian and Service, 1998). Beam trawling was reported to result in a 58% decrease in some taxa on naturally stable sediments which may lead to the long-term changes in benthic community structure (Kaiser and Spencer, 1996). Side scan sonar is a recognised technique for revealing evidence of trawling over wide areas (Smith and Rumohr, 2005; Harris, 2012), while a camera or video towed on a drop frame can provide detailed images of trawl scars and biological communities with minimal disturbance (Smith and Rumohr, 2005).

In May 2015 Marine Scotland Science conducted a survey on board the MRV Scotia at seven stations coincidental with oil and gas pipelines in the northern North Sea. These stations were selected based on a study using VMS data which found an aggregation of fishing around these areas (Rouse et al., 2017). Side scan sonar was carried out over the pipelines and TV tows were conducted perpendicular to the pipeline. The purpose of this survey was firstly to gain evidence of trawling in the vicinity of the pipelines and secondly to assess the impact on the surrounding seabed. This report firstly details the biotopes classified from the videos and photographs and secondly presents evidence for trawl scars from the side scan and the photographs. The effect of trawling on abundance of benthic invertebrates is investigated using two measures: the total count of organisms recorded on a photograph frame and the total number of sea pens recorded on a frame. Being
widespread on muddy ground and vulnerable to trawling, sea pens in particular provide an ideal test case for the benthic impact of trawling in the vicinity of oil and gas pipelines.

**Methods**

**Side scan sonar**

Seven stations were surveyed over four pipelines in May 2015 (Table 1, Figure 1). An Edgetech side scan sonar was towed at a speed of approximately 5 knots in lines parallel to the pipelines covering an area 500 m either side of them, over a distance of between 11 and 12.8 kms. The depth of the tow above the seabed (approximately 15 m) was optimised for the speed and stability of the vessel and the bottom topography enabling the visualisation of trawl scars. A Scout USBL system (Sonardyne) recorded the exact position of the side scan. The side scan sonar data were analysed following standard software guidelines using the software Caris Hips and Sips, v. 9. Errors were found in these data at three of the stations when processing the USBL data and a final surface could only be produced for four of the seven stations (Table 1).

**Table 1. Stations surveyed using side scan, video and photographs**

<table>
<thead>
<tr>
<th>Station</th>
<th>Pipeline name</th>
<th>Area surveyed by side scan</th>
<th>Date surveyed</th>
<th>Number of video transects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station 1</td>
<td>Forties C to Cruden Bay (PL8 &amp; PL721)</td>
<td>13.5 km²</td>
<td>21/05/2015</td>
<td>5</td>
</tr>
<tr>
<td>Station 9</td>
<td>Forties C to Cruden Bay (PL8 &amp; PL721)</td>
<td>13.1 km²</td>
<td>23/05/2015</td>
<td>7</td>
</tr>
<tr>
<td>Station 19</td>
<td>Brent A to St Fergus (FLAGS)</td>
<td>11.3 km²</td>
<td>25/05/2015</td>
<td>6</td>
</tr>
<tr>
<td>Station 20</td>
<td>Brent A to St Fergus (FLAGS)</td>
<td>no side scan</td>
<td>25/05/2015</td>
<td>4</td>
</tr>
<tr>
<td>Station 21</td>
<td>Nyhamna Sleipner R</td>
<td>no side scan</td>
<td>14/05/2015</td>
<td>3</td>
</tr>
<tr>
<td>Station 23</td>
<td>Kollsnes Sleipner R</td>
<td>12.2 km²</td>
<td>18/05/2015</td>
<td>6</td>
</tr>
<tr>
<td>Station 24</td>
<td>Kollsnes Sleipner R</td>
<td>no side scan</td>
<td>17/05/2015</td>
<td>6</td>
</tr>
</tbody>
</table>

**Video and camera deployment**

A drop-frame TV camera system was towed behind the vessel at ~1 knot. A digital stills camera (Canon) was mounted on the drop-frame together with a high definition and standard definition video (Kongsberg Simrad). The drop-frame was suspended 1 m above the seabed, guided by a steel weight attached by a line to the drop-frame. Maintaining the steel weight (63.5 mm diameter) on or just above the seabed ensured the correct height for accurate focussing of the video and digital camera. Video was recorded continuously together with digital photographs taken at one minute intervals for the duration of the transect including the pipeline feature itself. Two laser pointers set 68 mm apart provided a scale for identifying features.

The TV tows were conducted along a transect perpendicular to the pipeline extending to 500 m either side of it, for a duration of between 30 to 45 minutes. A
minimum of three TV tows were carried out at regular intervals along each stretch of pipeline. The location of the drop-frame and the digital stills were recorded directly into ArcView. The substrate and macrobenthos were recorded every minute of the tow.

Photograph and video analysis

The photographs were analysed in Adobe Photoshop Elements 14 for substrate type, species presence, total number of sea pens, total number of all invertebrate species and evidence of trawling. A grid was projected over the photograph to standardise the area (0.65 m²) in which species were identified and counted and trawl marks were noted. The species were identified to as high a level as possible. Burrows of *N. norwegicus* were distinguished from those of other species by their horse-shoe like shape. A burrow complex was counted as one individual (ICES, 2008). Sea pens were counted when visibly projecting out of their burrow. A trawl mark was distinguished from other marks on the seabed by their straightness (Annex I). Animal tracks, such as those left by decapods, are generally not straight.

Biotopes were allocated based on the substrate and species present according to the Marine Habitat Classification (Connor *et al.*, 2004). As the area covered by the photograph was less than 25 m², biotope presence was verified on the corresponding video. Poor quality photographs were not analysed and abundance counts were not carried out on images that were taken too close to the seabed. The videos were analysed qualitatively for substrate type, species presence, evidence of trawling and biotope.

Statistical analysis

Structure of the data

The data comprised counts of individual invertebrates within a total of 783 area-standardised photographic ‘frames’ (each 0.65 m²) from between three and seven ‘transects’ at each of seven ‘stations’. Individual frames are categorised as being ‘trawled’ or ‘untrawled’ on the presence of indicative markings left by the trawls.

Two observation variables were analysed. These are:

- The abundance of invertebrates on natural substrates (frames with pipelines were excluded). Counts vary between zero (418 frames) to 28 (one frame).
- The abundance of sea pens. A subset of the data comprising counts within a total of 441 frames from one to six transects at each of six stations. Counts used in the analysis exclude the pipeline themselves. Only transects with at least one sea pen present were retained in order to limit the study to stations that contained favourable substrates for sea pen establishment. Counts vary between zero (342 frames) and five (two frames).

Data editing

Zero counts were present for a large number of frames and could generate problems with fitting a satisfactory model. By summing counts across frames categorised as either trawled or untrawled within transects, it is possible to substantially reduce the occurrence of zero counts while retaining all of the explanatory variables structural to
the study; these are hereafter referred to as ‘summed frames’. Standardisation of the areas covered by summed frames is facilitated by additionally recording the constituent number of frames. Not all transects or stations contain both trawled and untrawled frames. These have, however, been retained for analysis to improve the estimates of site and transect variation.

**Statistical analysis**

The analyses undertaken comprise estimating:

1. The association between trawling and the total abundance of invertebrates.
2. The association between trawling and the abundance of sea pens.

Mean abundances were calculated and 95% confidence intervals (CI) estimated using a bootstrap corrected for bias and acceleration (Efron, 1987). Confidence intervals are approximate given that one of the estimations involved end point values.

The CI confounds uncertainty around the estimate of the association between abundance and trawling with variation between stations and transects. Generalised linear mixed models (GLMM) (McCullagh and Nelder, 1989) were used to partition the variation for each of these explanatory variables. The model used for both analyses is:

\[
\log(E(y_{ijk}|u_{jk})) - \log(x_{ijk}) = \beta_0 + \beta_1.x_i + \beta_2.x_j + u_{jk}
\]

where \(y_{ijk}\) = abundance of either 1) invertebrates or 2) sea pen in summed frames associated with trawled status \(i\) in transect \(k\) within site \(j\) (0 to 144 or 46) assuming a Poisson distribution; \(\beta_0\) = intercept; \(\beta_1\) = fixed effect of trawled category \(i\) (trawled, untrawled); \(\beta_2\) = fixed effect of site \(j\) (1 to 7 or 6); \(u_{jk}\) = random effect of transect \(k\) within site \(j\); \(x_{ijk}\) = number of constituent frames comprising summed frame for trawled category \(i\) in transect \(k\) within site \(j\). Models were estimated using penalized least squares. Stations were modelled as fixed rather than random effects because this gave rise to improved model diagnostics. Evidence for an association between the abundance and trawled category was obtained using a likelihood ratio test of nested models including and excluding \(\beta_1\) for which exploratory probability values \((p_{exp})\) for a type I error of no greater than 0.05, assuming no difference in abundance between trawled and untrawled frames, were categorised as statistically significant. The coefficient \(\beta_1\) provides, after exponentiation, an estimate of relative abundance of trawled compared to untrawled areas with the 95% CI calculated from the profile likelihood.

Analyses were performed within the R statistical environment (Ihaka and Gentleman, 1996) version 3.3.3 utilising the supplementary R packages boot 1.3-18 (for the bootstrap) and lme4 1.1-12 (for GLMM) (Bates et al., 2015).

**Results**

The biotopes identified across the stations are displayed in Figure 1. Photographic examples of these biotopes are given in Annex I. Annex II contains the biotopes allocated for the video. The biotopes of the photographs are available as a dataset at [http://doi.org/10.7489/12117-1](http://doi.org/10.7489/12117-1). Four biotopes were recorded; “offshore circalittoral
“mud” (SS.SMu.OMu), “sea pens and burrowing megafauna in circalittoral fine mud” (SS.SMu.CFiMu.SpnMeg), “offshore circalittoral mixed sediment” (SS.SMx.OMx) and “circalittoral sand” (SS.SSa.OSa). Evidence of trawling was found at all stations except 9 (Nyhamna Sleipner R pipeline) and 21 (Forties C to Cruden Bay pipeline) (Figure 1).

Figure 1. Biotopes and evidence of trawling present in the 7 survey areas.

Forties C to Cruden Bay

Stations 1 and 9 were located on the same pipeline within 20 km of each other and displayed similar biotopes; burrowed mud (SS.SMu.OMu), mud with sea pens and burrowing megafauna (SS.SMu.CFiMu.SpnMeg), mixed sediments (SS.SMx.OMx) and sand (SS.SSa.OSa) (Figure 2). Burrowing species such as *N. norwegicus* inhabited the sand and the sea pen *P. phosphorea* was widespread on the muddier substrate. Other frequent species recorded were *V. mirabilis*, *Sabella sp.*, *Urticina sp.* and starfish such as *Stichastrella rosea*. Evidence of trawling is widespread. Large sweeps running diagonally across the pipeline can be seen on the side scan at station 1 and to a lesser extent at station 9. Trawl marks are present in many of the photographs and video at station 1 (TV runs 1 to 4, Annex I and II). The pipeline lies proud of the seabed (darker line running along the centre of the side scan image) and has an accumulation of gravel immediately to the side of it. The pipeline itself harbours a rich covering of hydroid/bryozoan turf together with anemones and hermit crabs.
The predominant biotope identified at Station 19 was mud with sea pens and burrowing megafauna (Figure 4). *P. phosphorea* was widespread with occasional...
sittings of *V. miribalis*. There were high densities of burrowing fauna particularly *N. norwegicus* but also burrows of worms, anemones and other decapods. Rock dump was found at TV3 close to the pipeline. The community on the rock dump was typical of loose cobbles and pebbles and contained hydroids, starfish and crabs (Annex I). The pipeline itself was rich with *Caryophyllia smithii*, hermit crabs, anemones and hydroids or bryozoans. No photographic or video evidence of trawling was recorded at station 19. Potential trawl scars are visible on the side scan, such as inset B on Figure 4 (TV4).

Due north on the same pipeline at station 20, there was much photographic evidence of trawling but side scan images could not be post-processed. The biotope at TV1 and part of TV2 was mud with sea pens and burrowing megafauna. Both *P. phosphorea* and *V. miribalis* were present and burrows of *N. norwegicus*. TV2 to 4 were characterised by burrowed mud and mixed sediment. A rich community of starfish, urchins, sea cucumbers and sponges were found on the mixed sediment. The sea anemone *Bolocera tuediae* was common as was the calcareous worm *Hyalinoecia tubicola*. The pipeline was covered in a hydroid/bryozoan turf.
The biotopes found at station 23 on the Kollsnes Sleipner R pipeline are SS.SMx.OMx and SS.SMx.OMx (Figure 5). Frequent occupants of this habitat are anemones such as *B. tuediae*, urchins, sponges and starfish. Clear trawl tracks crossing over the pipeline were recorded on the side scan on the northern section of the survey area, while the southern section appears less disturbed. However, evidence of trawling can be seen on all TV runs crossing the station. The trawl marks are more visible where the side scan has passed over rougher ground (TV1 to 4). Fauna such as anemones, starfish and calcareous tubeworms were recorded on the pipeline. Fish were sheltering next to or underneath it.
The sea bed substrates at station 24 are more diverse, ranging from mud to sands, gravels and occasional boulders. Consequently, a greater variety of species were occupying these different habitats, such as urchins, starfish, hermit crabs, occasional *V. miribalis* and burrowing species such as anemones, *N. norwegicus* and sea cucumbers. The pipeline itself was occupied by anemones and juvenile fish clustering around it. Trawl marks are evident at this site. The bobbins appear to leave a furrowing mark in the sediment (Annex I).

**Figure 5. Side scan images of station 23 on the Kollsnes Sleipner R pipeline**

**Effect of trawling on the total abundance of invertebrates**

Mean values and confidence intervals (CI) are presented in Figure 6a. The CI, which includes variation between stations and transects within stations, overlap.

The relative abundance for trawled relative to untrawled summed frames, as estimated by the GLMM, is 0.63 (with 95% CI of 0.44 to 0.87). This difference is
categorised as statistically significant ($\chi^2=8.032$ for 1 degree of freedom (df), $p_{exp}=0.005$).

Model diagnostics are regarded as being satisfactory. There is evidence of an association between trawling and a reduction in the abundance of invertebrates.

**Effect of trawling on the abundance of sea pen**

Mean abundances and CI are presented in Figure 6b. The CI, which includes variation between stations and transects within stations, overlap.

The relative abundance for trawled relative to untrawled summed frames, as estimated by the GLMM, is 0.32 (0.10 to 0.79). This difference is categorised as being statistically significant ($\chi^2=6.698$ for 1 df, $p_{exp}=0.010$).

Model diagnostics are not satisfactory with evidence of:

- a high outlying sea pen count from an untrawled summed frame with the potential to exert leverage,
- and under-dispersion (dispersion-ratio = 0.47).

However, deletion of the outlying observation substantially improves the diagnostics of the model and generates similar results.

There is evidence of an association between trawling and a reduction in the abundance of sea pen. It is likely, however, that the number of stations is only just sufficient to detect this association and additional data to confirm the result is desirable.

![Figure 6](image)

**Figure 6.** Mean abundances with 95% CI of trawled and untrawled frames in a 0.65 m$^2$ area for (a) the total abundance of invertebrates and (b) the abundance of sea pens.

**Discussion**

This study provides evidence of an association between trawling and a reduction in the total abundance of invertebrates and specifically the total abundance of sea pens in the northern North Sea. This strengthens the evidence of the negative effect of
bottom trawling on benthic fauna (Kaiser and Spencer, 1996; Dayton et al., 1995; Tuck et al., 1998; Jennings et al., 2001). The side scan imaging coupled with the video and photographs, clearly reveals evidence of trawling around the pipelines. This confirms the finding of Rouse et al. (2017) that fisheries do target oil and gas pipelines in the North Sea. The study demonstrates that the elevated fishing effort in the vicinity of the pipelines has a negative effect on sea pens and other benthic invertebrates. These results provide further insights into decisions on decommissioning of such pipelines.

The study also extends knowledge of the known distribution of sea pens in this region. These photographic records confirm that they occur far out into the North Sea where habitat is suitable for them, i.e. on mud or fine sand. This is in keeping with predicted habitat models of sea pen distribution which suggest that the habitat suitability increases with mud content (Greathead et al., 2015). Habitat mapping in this offshore area of the North Sea has been carried out from predicted data (EMODnet, 2017). Records from this study could be incorporated into finer scale habitat maps using actual sampling data.

Although, the analysis of the impact of trawling on sea pens could have benefited from additional sampling stations in which they were present, the study is still able to demonstrate a likely reduction of sea pens in areas where trawling took place. There are several factors that could have affected the results however. Both P. phosphorea and V. miribalis are able to retract into their burrows in response to predation (Kinnear et al., 1996), which could result in a lower abundance count on the frames. However, the burrows are still visible even if the sea pen has retracted inside it. Further to this, empty burrows were rarely encountered on trawled sediment, so the effect could only lead to an underestimation of the impact of sea pens by trawling.

Another factor that could not be accounted for was the age of the trawl marks and the history of trawling in the study sites. How long it takes for the trawl marks to fade in such a low energy environment is not known, nor do we know the length of time for P. phosphorea and V. miribalis to re-grow or to re-colonise an area after it has been trawled. Kinnear et al. (1996) simulated the effect of static creeling on sea pens. V. miribalis retracted into its burrow and P. phosphorea was able to re-anchor itself once it touched the mud but static creeling is a much more benign method of fishing than a mobile demersal trawl. If these species are able to re-establish themselves before the trawl marks have faded it would result in an underestimate of the effect of trawling on sea pens. Likewise, we may also see an underestimate in the effect on total abundance of invertebrates but recovery rates after trawling are species-specific. Long-lived gastropods, bivalves and fragile species such as urchins are the most affected by mobile trawling. Scavengers, such as starfish, crabs and small polychaetes may accumulate in large numbers as a result of disturbances (Kaiser et al., 2000; Jennings et al., 2001). Small polychaete worms are present on the trawled areas at station 24 on the Kollsnes Sleipner R pipeline.

Similar to the present study, Greathead et al. (2004) report that the population median of F. quadrangularis (the tall sea pen) is lower at a more heavily trawled site on the west coast of Scotland than a less trawled one. In the present study it is possible to determine the likely effect of trawling at the scale of an individual photograph (<1 m²), while the site effect can also be accounted for in the model. This is beneficial as we can account for the variation in trawling within a site. We also
recorded other species that were only present in sites where no trawling had taken place such as anemones and sponges. These species are often larger and non-mobile.

Analysis of the side scan imaging coupled with the video and photographs, clearly shows that trawling does take place within 500 m either side of the pipelines. The trawl marks on the side scan appear to sweep over the pipelines and back again (e.g. stations 1 and 23). These marks are likely made by the otter boards used to spread the gear on demersal trawls, such as those used for Nephrops fishing or a mixed demersal fishery (Galbraith et al., 2004). Other marks on the side scan imaging appear to be isolated striations (e.g. at station 19). These striations are likely formed when an otter board rides over an obstacle, such as a rock or a pipeline, and rebounds on the seabed with greater force leaving a depression on the seabed. Many of the photographs show repeated horizontal striations indicative of ground gear which creates a furrowed appearance. The ground gear comprises of spacers and different diameters of rubber discs attached to the foot rope of the net (Galbraith et al., 2004). Where such trawl marks are present, there is often just barren sediment with no megafauna at all. As is reported by Maggorian and Service (1998), the ground gear effectively scrapes the top layer of sediment and removes any emergent epifauna. These trawl marks may be present on the seabed for a long time because it is a low energy environment. Understanding the recovery rate of the benthos relative to the intensity of trawling is likely to be key to determining whether the demersal fishery is sustainable.

The study by Rouse et al. (2017) analysed VMS data on a North Sea scale and clearly shows that fisheries do target oil and gas pipelines. This study provides evidence directly from the field that fishing is taking place around these pipelines. Trawl marks are clearly visible from the side scan, video and photographs. It is thought that fisheries target oil and gas pipelines because of the reef effect they create which leads to greater numbers of fish and higher catches around the pipeline (Hunter and Sayer, 2009). Although fish were not quantified in this study, they were seen to cluster to the side or underneath the pipelines. Those fish that were recorded were usually the juveniles. The larger individuals, that were big enough to be of commercial value, such as Gadus morhua or Lophius piscatorius, were typically seen further from the pipeline. It is possible that fish are attracted to the pipeline for shelter and forage in the surrounding area (Sarno et al., 1994). An understanding of the type of fishery taking place at these stations, i.e. whether boats are targeting ground fish or Nephrops or both, would help confirm the reasoning for the increased trawl activity close to the pipelines.

The pipelines themselves harboured an assemblage of species typical of a hard substrate, such as Ascidians, Caryophyllia smithii, hermit crabs and anemones. There was also an accumulation of gravels next to the pipeline which were occupied by a community of species typical of coarser substrate, such as starfish and decapods. These coarser substrates occurred in the immediate vicinity of the pipeline however, and the substrate quickly reverted to its original composition (usually sand or mud) a few metres away. No non-native species were identified on the pipelines but the communities recorded would not otherwise be present at these stations if the pipelines were not there. Results from these pipelines at the time they were sampled, would suggest that concerns over species of conservation interest or non-native species residing on the pipeline, do not need to be considered in the
decision making process over whether the pipelines should be fully removed or not. However, the greater fishing intensity on the area surrounding the pipeline and the impact this is having on the benthos does require consideration.

Conclusion

This study provides evidence that the abundance of benthic fauna is reduced by trawling on burrowed mud and sand. Both burrowed mud and the component species of the habitat are of key conservation importance and recommended for protection. The burrowed mud habitat associated with sea pens is widespread in the North Sea but it is also the focus of the Nephrops fishery. Thus conservation efforts must be balanced by fisheries interests. Together with the evidence from VMS studies (Rouse et al., 2017), this study furthers the evidence for elevated fishing around oil and gas pipelines in the North Sea. Where burrowed mud and pipelines coincide, there is potential for a greater impact on the sea pens from fisheries. In order to achieve a clear seabed pipelines would need to be removed during decommissioning. However, if technology for the removal of larger diameter pipelines does not exist or is too costly, an alternative solution may be to trench and bury the pipeline in situ. Trenching and burying a pipeline would have the same effect as removing it by eliminating a surface environment for fish aggregation. This would return the habitat to a condition that would enable the expansion of PMF species and reduce the frequency of future fishing effort for the area.

Future studies might also consider the scale of the impact associated with the elevated fishing intensity around surface laid pipelines, particularly those that coincide with sandy mud and muddy environments typical of Nephrops and sea pens. Following on from this, we need to consider the life cycle of pipelines that are likely to be decommissioned. While in operation surface laid pipelines appear to present an acceptable risk to fishers. However, the onset of pipeline degradation post decommissioning will increase the snagging risk significantly. Are there options available to reduce the risk to an acceptable level and what scale of impact will the resulting demersal fishing have on the benthic fauna? We conclude that the operators and the regulators of oil and gas pipelines are advised to consider fishing intensity and presence of sensitive habitats in the decision making process of decommissioning oil and gas pipelines.

References


JNCC (2015). The Marine Habitat Classification for Britain and Ireland Version 15.03 (accessed 01/03/2017). [http://jncc.defra.gov.uk/MarineHabitatClassification/](http://jncc.defra.gov.uk/MarineHabitatClassification/)


Marine (Scotland) Act (2010) asp5


**Acknowledgements**

We are grateful to Philip Copland for setting up the side scan, to Jim Hunter for operating the drop frame TV and to the rest of the crew on board the MRV Scotia for collecting the data. We would also like to thank Mike Robertson for taxonomic expertise, David Bova for advice about fishing gear and Nichola Lacey for reviewing the manuscript.
Annex I. Photographs of the biotopes identified in the study. Priority marine features are labelled in red.
SS.SMx.OMx - Offshore circalittoral mixed sediment with *Callionymus lyra*  
Forties C to Cruden Bay (PL8 & PL721), Station 9, TV6, 3590

Offshore circalittoral mud with *Hyalinoecia tubicola*  
Brent A to St Fergus (FLAGS) Station 20, TV3, 3852

SS.SMx.OMx - Offshore circalittoral mixed sediment  
Kollsnes Sleipner R, Station 23, TV1, 3327

SS.SMu.CFiMu – Circalittoral fine mud with occasional boulders. *Bolocera tuediae* and carapace of *Lithodes maia*  
Kollsnes Sleipner R, Station 23, TV2, 3357

SS.SMx.OMx - Offshore circalittoral mixed sediment with shells, hydroids and Paguridae  
Brent A to St Fergus (FLAGS) Station 19, TV3, 3726
Pipeline on SS.SMx.OMx - Offshore circalittoral mixed sediment
Forties C to Cruden Bay (PL8 & PL721), Station 9, TV3, 3518

Pipeline on SS.SMx.OMx - Offshore circalittoral mixed sediment
Forties C to Cruden Bay (PL8 & PL721), Station 1, TV5, 3598

Scraped pipeline with Bolocera tuediae
Kollsnes Sleipner R, Station 23, TV4, 3411

Scraped pipeline with Caryophyllia smithii and Bolocera tuediae
on SS.SMu.OMu - Offshore circalittoral mud
Kollsnes, Sleipner R, Station 23, TV1, 3335

Rock dump with hydroid turf, Hippasteria phrygiana and Stichastrella rosea
Brent A to St Fergus (FLAGS), Station 19, TV3, 3737

Pipeline with ascidian and hydroid turf, Bolocera tuediae,
burrowing anemone and juvenile fish on SS.SMu.OMu with occasional gravel
Kollsnes Sleipner R Station 23, TV3, 3387
Barren SS.SMu.OMu with bobbin marks from a trawl
Kollsnes Sleipner R, Station 23, TV3, 3388

Barren SS.SMu.CFiMu.SpnMeg with bobbin marks. Note, the sea pen component of this biotope is present in the video.
Brent A to St Fergus (FLAGS), Station 20, TV1, 3803

SS.SMu.CFiMu.SpnMeg – offshore circalittoral sand with bobbin marks and Virgularia mirabilis
Kollsnes Sleipner R, Station 23, TV4, 3409

SS.SMu.OMu with bobbin marks and numerous small worm casts
Kollsnes Sleipner R, Station 24, TV1, 3151

Barren offshore circalittoral mud (SS.SMu.OMu) with trawl marks
Kollsnes Sleipner R, Station 23, TV2, 3355

SS.SMu.CFiMu.SpnMeg with P. phosphorea and burrows of Nephrops norvegicus. Trawl marks visible on the surface.
Forties C to Cruden Bay, Station 1, TV3, 3560
Annex II. Description of videos, including position, substrate, evidence of trawl marks, depths, pipeline crossing time, biota, interpretation of biotopes and presence of priority marine features

<table>
<thead>
<tr>
<th>Pipeline, Station, TV run and date</th>
<th>Start latitude</th>
<th>Start longitude</th>
<th>End latitude</th>
<th>End longitude</th>
<th>Substrate</th>
<th>Trawl marks present</th>
<th>Depth at start (m)</th>
<th>Depth at finish (m)</th>
<th>Time of pipeline crossing on video</th>
<th>Biota</th>
<th>Biotope</th>
<th>Priority Marine Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nyhamna Sleipner R Stn 21 TV1 14-05-15</td>
<td>60.03617</td>
<td>3.022232</td>
<td>60.03226</td>
<td>3.015813</td>
<td>fine sand no</td>
<td>123</td>
<td>123</td>
<td>not present</td>
<td>Psammechinus miliaris, Asturias rubens</td>
<td>SS.SM.CfMu</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Nyhamna Sleipner R Stn 21 TV2 14-05-15</td>
<td>59.99952</td>
<td>3.00693</td>
<td>59.99632</td>
<td>3.001575</td>
<td>fine sand no</td>
<td>123</td>
<td>123</td>
<td>not present</td>
<td>Psammechinus miliaris, Hyalinoecia tubicola</td>
<td>SS.SSаІOSаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Nyhamna Sleipner R Stn 21 TV3 14-05-15</td>
<td>59.96256</td>
<td>2.997786</td>
<td>59.96212</td>
<td>2.990382</td>
<td>fine sand no</td>
<td>124</td>
<td>122</td>
<td>not present</td>
<td>Psammechinus miliaris, Hippasteria phrygiana, Paguridae</td>
<td>SS.SSаІOSаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 24 TV1 17-05-15</td>
<td>59.26792</td>
<td>3.065425</td>
<td>59.26714</td>
<td>3.040857</td>
<td>fine sand, mixed cobbles and pebbles yes</td>
<td>135</td>
<td>130</td>
<td>not present</td>
<td>Psammechinus miliaris, Asturias rubens, Epizoanthus incrustatus, Asturias rubens, Paguridae</td>
<td>SS.SSаІOSаІ, SS.MMаІOMаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 24 TV2 17-05-15</td>
<td>59.27208</td>
<td>3.051767</td>
<td>59.271613</td>
<td>3.07087</td>
<td>fine sand, shells, rock, sand and gravel no</td>
<td>130</td>
<td>135</td>
<td>03:22:48</td>
<td>Bolocera tuediae, Psammechinus miliaris, Asturias rubens, Hyalinoecia tubicola, Paguridae, Myxine glutinosa, Lophius piscatorius; anemones and juvenile fish on side of pipeline</td>
<td>SS.SSаІOSаІ, SS.MMаІOMаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 24 TV3 17-05-15</td>
<td>59.28027</td>
<td>3.09266</td>
<td>59.28013</td>
<td>3.067981</td>
<td>fine sand yes</td>
<td>137</td>
<td>132</td>
<td>04:14:23</td>
<td>Asturias rubens, Stichastrella rosea, Psammechinus miliaris, Stichopus tremulus, Hyalinoecia tubicola, Nephrops norwegicus, Myxine glutinosa, Bolocera tuediae on side of pipeline</td>
<td>SS.SSаІOSаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 24 TV4 17-05-15</td>
<td>59.29106</td>
<td>3.068687</td>
<td>59.29092</td>
<td>3.101895</td>
<td>fine sand, rock yes</td>
<td>134</td>
<td>138</td>
<td>07:05:00</td>
<td>Psammechinus miliaris, Paguridae, Nephrops burrows, Asturias rubens, Pectinidae, Stichopus tremulus, worm burrows, Myxine glutinosa</td>
<td>SS.SSаІOSаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 24 TV5 17-05-15</td>
<td>59.33493</td>
<td>3.160858</td>
<td>59.33391</td>
<td>3.137638</td>
<td>fine sand, burrowed sand yes</td>
<td>142</td>
<td>140</td>
<td>not present</td>
<td>Nephrops burrows, Psammechinus miliaris, burrowing anemone, Stichopus tremulus, Bolocera tuediae, Myxine glutinosa</td>
<td>SS.SSаІOSаІ</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 24 TV6 17-05-15</td>
<td>59.33973</td>
<td>3.141673</td>
<td>59.34159</td>
<td>3.156045</td>
<td>no video no video</td>
<td>141</td>
<td>142</td>
<td>no video</td>
<td>no video</td>
<td>no video</td>
<td>none</td>
<td></td>
</tr>
</tbody>
</table>

22
<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinates</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kollsnes Sleipner R Stn 23 TV1 18-05-15</td>
<td>58.97904, 2.6935</td>
<td>Fine sand, mixed sand and gravel, fine sand with gravel; yes; 120; 120; 13:15:00; Bolocea tuediae, unidentifiable anemones, Astropecten irregularis, Asteroidea, Porifera, juvenile fish; Bolocea, Metridium sp. and Salmacina sp. on side of pipeline</td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 23 TV2 18-05-15</td>
<td>58.95831, 2.676523</td>
<td>Fine sand, sand and gravel; yes; 120; 120; 03:27; Stichastrella rosea, Astropecten irregularis, Metridium sp., Bolocea tuediae, Pennatula phosphorea; Bolocea on side of pipeline</td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 23 TV3 18-05-15</td>
<td>58.95007, 2.653912</td>
<td>Fine sand, sand and gravel, sand and cobbles, angular boulders; yes; 121; 120; 14:33; Bolocea tuediae, Pennatula phosphorea, Stichastrella rosea, Astropecten irregularis, Echinus sp., Axinella infundibuliformis, Porifera; anemones on the side of pipeline, fish sheltering underneath pipeline</td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 23 TV4 18-05-15</td>
<td>58.94861, 2.653918</td>
<td>Fine sand; yes; 121; 120; 14:20; Pennatula phosphorea, Bolocea tuediae, Astropecten irregularis, Stichastrella rosea, Asturias rubens, Nephrops burrow, tube anemone; Bolocea, Helicolenus dactylopterus and unidentifiable teleost fish on or under pipeline</td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 23 TV5 18-05-15</td>
<td>58.94533, 2.649707</td>
<td>Fine sand; yes; 122; 123; 10:34; Pennatula phosphorea, Virgularia mirabilis, Stichastrella rosea, Astropecten irregularis, Asturias rubens, Nephrops norwegicus, Bolocea tuediae, unidentifiable anemones on side of pipeline</td>
</tr>
<tr>
<td>Kollsnes Sleipner R Stn 23 TV6 18-05-15</td>
<td>58.92001, 2.617477</td>
<td>Fine sand, burrowed sand, fine sand with shells; yes; 121; 120; 22:06, 25:21; Pennatula phosphorea, Virgularia mirabilis, Bolocea tuediae, Astropecten irregularis, Choristes philippi, Nephrops burrow, Hyalinoecia tubicola; Bolocea tuediae and Stichastrella rosea on pipeline</td>
</tr>
<tr>
<td>Forties C to Cruden Bay Stn 1 TV1 21-05-15</td>
<td>57.637308, -0.182621</td>
<td>Fine sand, shelly sand; yes; 104; 106; 22:52; Pennatula phosphorea, Virgularia mirabilis, unidentified anemones, Majoidea, Asturias rubens, Scyltorhinus sp., Pleuronectiformes; hydroids and Paguridae on pipeline</td>
</tr>
<tr>
<td>Forties C to Cruden Bay Stn 1 TV2 21-05-15</td>
<td>57.635937, -0.206788</td>
<td>Fine sand, shelly sand; yes; 105; 108; 26:13; Pennatula phosphorea, Virgularia mirabilis, unidentified anemones, Asturias rubens, Astropecten irregularis, Stichastrella rosea, Hippasteria phyrgiana, Nephrops norwegicus, Myxine glutinosa, Pleuronectiformes, Paguridae with and without Hydractinia associated with pipeline</td>
</tr>
<tr>
<td>Forties C to Cruden Bay Stn 1 TV3 21-05-15</td>
<td>57.632511, -0.252207</td>
<td>Fine sand, shelly sand; yes; 107; 106; 37:58; Pennatula phosphorea, Virgularia mirabilis, Pleuronectiformes, Nephrops norwegicus, Asturias rubens, Paguridae with Hydractinia, Triglidae, unidentified anemones and hydroids on pipeline</td>
</tr>
<tr>
<td>Forties C to Cruden Bay Stn 1 TV4 21-05-15</td>
<td>57.625453, -0.294247</td>
<td>Fine sand, shelly sand, cable; no; 100; 100; 23:03; Pennatula phosphorea, Virgularia mirabilis, Nephrops norwegicus, Paguridae, Hyalinoecia tubicola, Asturias rubens, Holothurian, Sabella pavonina, bivalve displaying paired siphons, Myxine glutinosa, Triglidae, Raja sp., unidentified teleost fish</td>
</tr>
<tr>
<td>Station</td>
<td>Date</td>
<td>Lat/Long</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>C to C</td>
<td>21-05-15</td>
<td>57.625453</td>
</tr>
<tr>
<td></td>
<td></td>
<td>58.609551</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C to C</td>
<td>22-05-15</td>
<td>57.66579</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.668</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C to C</td>
<td>22-05-15</td>
<td>57.67056</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.66254</td>
</tr>
<tr>
<td>C to C</td>
<td>22-05-15</td>
<td>57.66775</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.67404</td>
</tr>
<tr>
<td>C to C</td>
<td>22-05-15</td>
<td>57.67951</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.67201</td>
</tr>
<tr>
<td>C to C</td>
<td>22-05-15</td>
<td>57.6693</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.67785</td>
</tr>
<tr>
<td>C to C</td>
<td>22-05-15</td>
<td>57.67826</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57.68268</td>
</tr>
<tr>
<td>A to S</td>
<td>24-05-2015</td>
<td>58.592485</td>
</tr>
<tr>
<td></td>
<td></td>
<td>58.593207</td>
</tr>
<tr>
<td>A to S</td>
<td>24-05-2015</td>
<td>58.609408</td>
</tr>
<tr>
<td>Location</td>
<td>Latitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
<td>---------------</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 19 TV3</td>
<td>58.625556</td>
<td>-0.989350</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 19 TV4</td>
<td>58.624989</td>
<td>-0.991624</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 19 TV5</td>
<td>58.648627</td>
<td>-0.991624</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 19 TV6</td>
<td>58.673454</td>
<td>-0.966858</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 20 TV1</td>
<td>59.898785</td>
<td>0.221013</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 20 TV2</td>
<td>59.930190</td>
<td>0.256007</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 20 TV3</td>
<td>59.942430</td>
<td>0.271973</td>
</tr>
<tr>
<td>Brent A to St Fergus Stn 20 TV4</td>
<td>59.960910</td>
<td>0.302672</td>
</tr>
</tbody>
</table>